Central exclusive χ_c production

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Main Topics

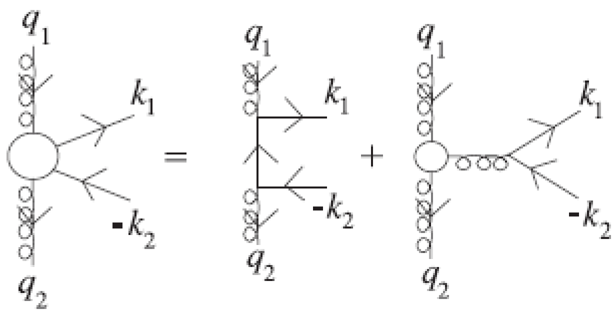
- QCD factorization and ‘Durham Model’
- Heavy quarkonia: inclusive and exclusive production
- Generalized (skewed) UGD and positivity
- Relative contributions of spin 0,1,2 for various UGD
- Helicity amplitudes
- Conclusions

QCD factorization

- Hard (calculable Perturbatively) vs Soft (Non-Perturbative but univesral) parts
- Collinear – transverse Perturbative (DGLAP)+ longitudinal NP (PDF)
- Kt- longitudinal Perturbative (BFKL)+transverse NP(Unintegrated Gluon Distributions)
- DGLAP/BFKL – P: different asymptotics of the same diagrams / NP Inputs

Meson Vertex

- BFKL evolution
- Finite mass – NLO BFKL – special vertex



- does not contribute for colour singlets

Production amplitude

- NRQCD:

$$\psi_{\chi}^{c_2 c_1} = \mathcal{P}(q\bar{q} \to \chi_{cJ}) \bullet \Psi^{c_2 c_1}$$
$$= \sum_{i,j} \sum_{L_z, S_z} \frac{1}{\sqrt{m}} \int \frac{d^4 q}{(2\pi)^4} \delta\left(q^0 - \frac{\vec{q}^2}{M}\right) \Phi_{L=1,L_z}(\vec{q})$$
$$\langle L=1, L_z, S=1, S_z | J, J_z \rangle \langle 3i, \bar{3}j | 1 \rangle Tr\left\{\Psi_{ij}^{c_2 c_1} \mathcal{P}_{S=1,S_z}\right\},$$

- P-wave

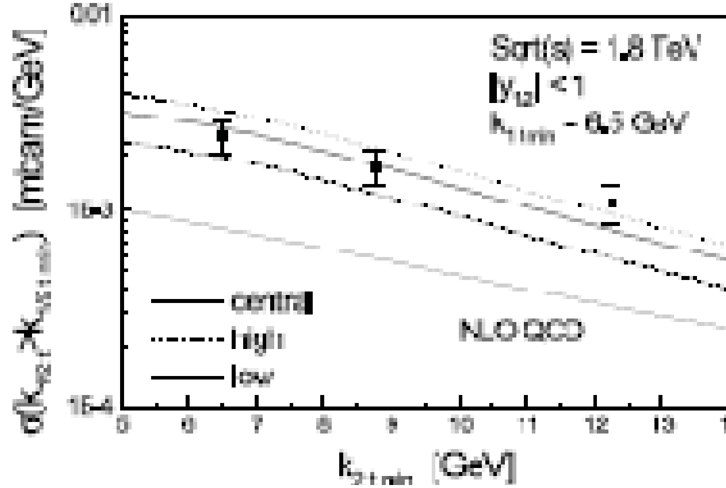
$$\int \frac{d^3\vec{q}}{(2\pi)^3} q^{\alpha} \Phi_{L=1,L_z}(\vec{q}) = -i\sqrt{\frac{3}{4\pi}} \epsilon^{\alpha}(L_z) \mathcal{R}'(0)$$

- J=1,2

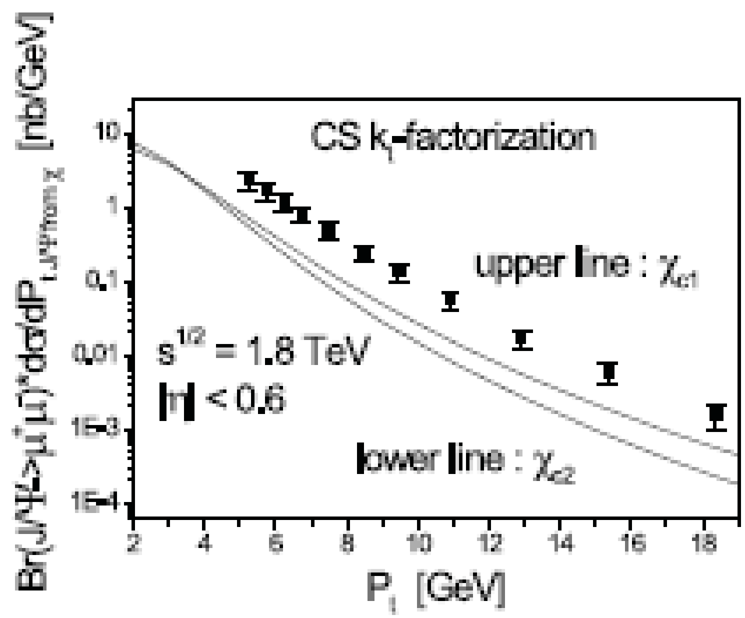
$$\sum_{L_z,S_z} \langle 1, L_z, 1, S_z | 1, J_z \rangle \, \epsilon^{\mu}(L_z) \epsilon^{\nu}(S_z) = -i\sqrt{\frac{1}{2}} \varepsilon^{\mu\nu\alpha\beta} \frac{P_{\alpha}}{M} \epsilon_{\beta}(J_z)$$
$$\sum_{L_z,S_z} \langle 1, L_z, 1, S_z | 2, J_z \rangle \, \epsilon^{\mu}(L_z) \epsilon^{\nu}(S_z) = \epsilon^{\mu\nu}(J_z)$$

Inclusive case: kT factorization vs CDF data (Hagler,Kirschner,Schafer, Szymanowski,OT)

- Open beauty
  Phys.Rev.D62:071502,2000.



- Inclusive χ_c
  Phys.Rev.Lett.86:1446-1449, 2001
- Landau-Yang "theorem" bypassed!

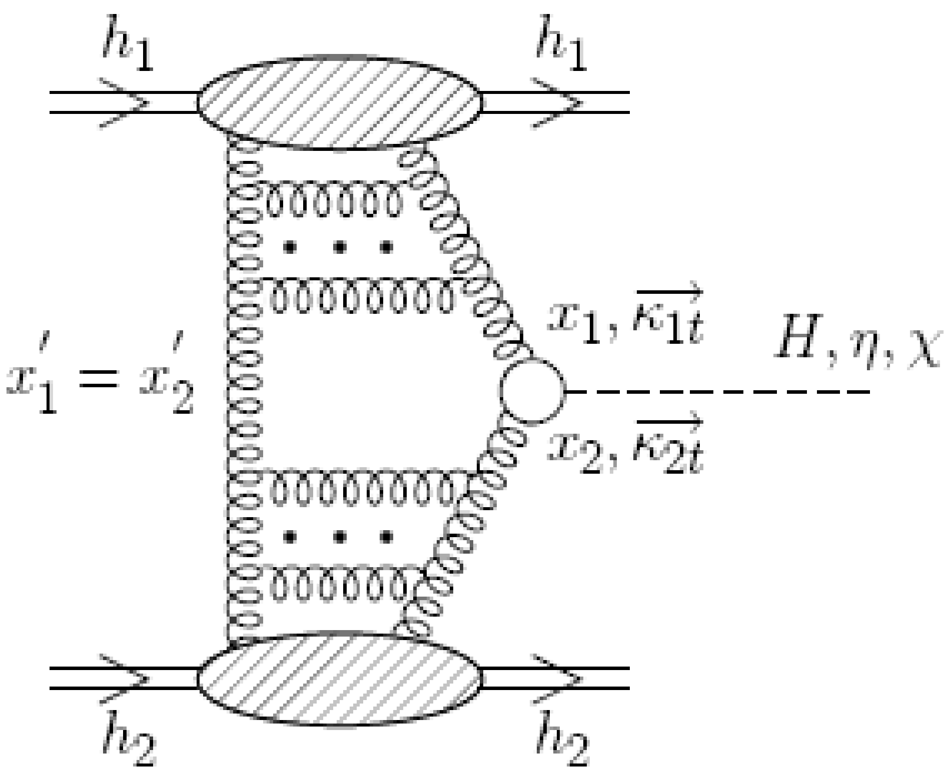


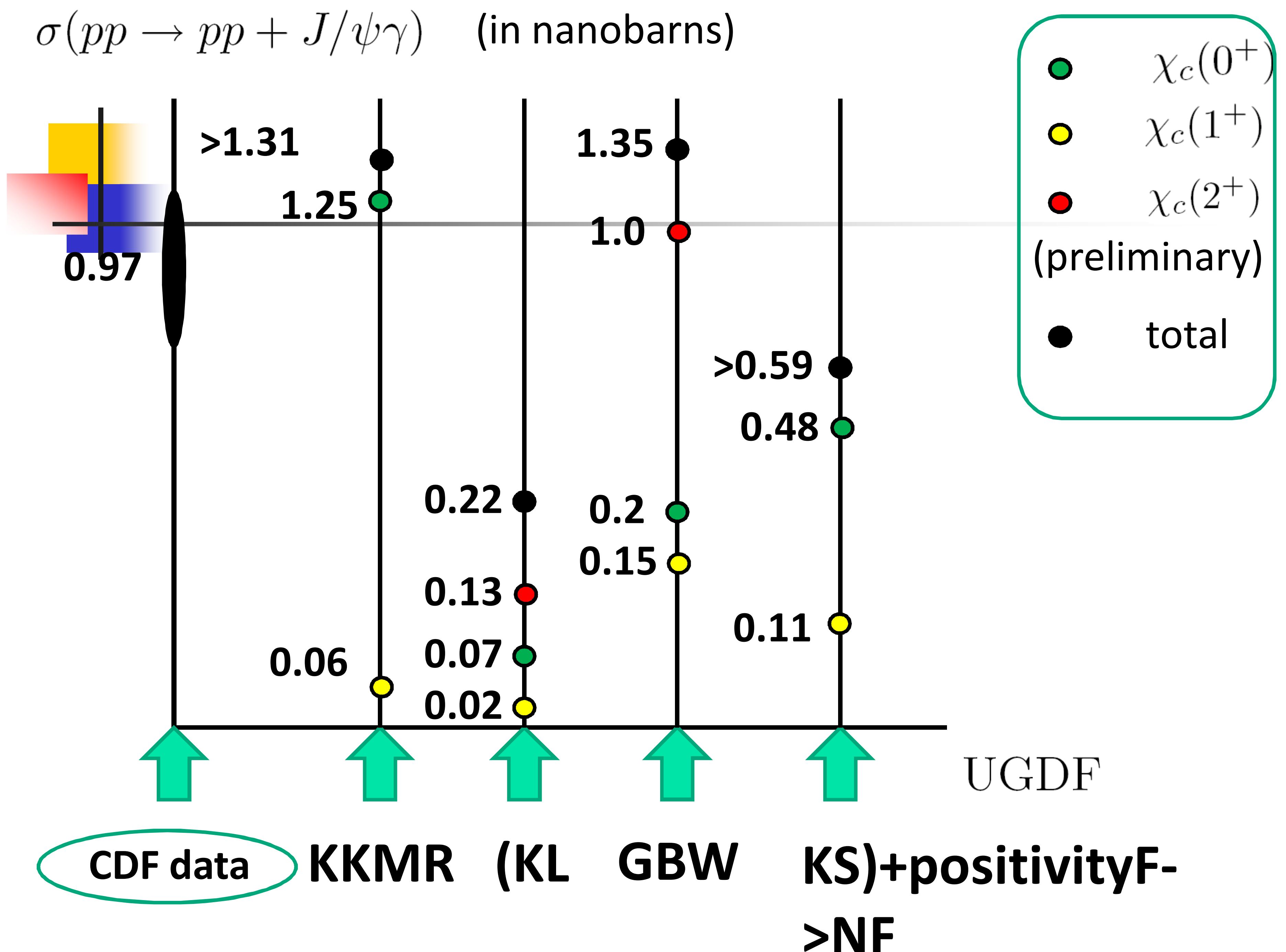
Exclusive processes

- Complicated – new P and NP ingredients
- Collinear – ERBL evolution + GPD's
- Kt-Generalzied UGD
- - difficulties in factorization proof

Standart approach - Durham (KKMR) Model

- Perturbative qq scattering -> hadrons
- Generalized Unintegrated Gluon Distributions
- Sudakov IR "regularization"
- NRQCD - same hard parts - factorization





$\sigma(pp \to pp + J/\psi\gamma)$ (in nanobarns)
$\chi_c(0^+)$
$\chi_c(1^+)$
$\chi_c(2^+)$
(preliminary)
total
>1.31
1.25
0.97
0.06
0.22
0.13
0.07
0.02
1.35
1.0
0.2
0.15
>0.59
0.48
0.11
UGDF
CDF data
KKMR
(KL
GBW
KS)+positivityF->NF

Density matrix positivity and GUGD

- General property (counterpart of unitarity) **Phys.Rept.470:1-92,2009**.

- NP matrix elements (and impact factors)

-parton (-hadron) density matrices
– Cauchy–Schwarz–Bunyakovsky - type inequalities
$|\langle A|B\rangle|^2 < \langle A|A\rangle\langle B|B\rangle$
Collinear GPD – Ryskin; Pire,Soffer,OT; Radyushkin; Pobylitsa
GUGD:

$$f_{g,1}^{\rm off}(x_1, x_1', k_{0,t}^2, k_{1,t}^2, t_1) \;=\; \sqrt{f_g^{(1)}(x_1', k_{0,t}^2, \mu_0^2) \cdot f_g^{(1)}(x_1, k_{1,t}^2, \mu^2)} \cdot F_1(t_1)$$

Saturation – for limited number (or correlation between) intermediate states (= effective dimension of vector space)

Role of small transverse momenta

$$\mathcal{M} = N \int \frac{d^2 q_{0,t} P[\chi_c(0^+)]}{q_{0,t}^2 q_{1,t}^2 q_{2,t}^2} f_g^{KMR}(x_1, x_1', Q_{1,t}^2, \mu^2; t_1) f_g^{KMR}(x_2, x_2', Q_{2,t}^2, \mu^2; t_2)$$

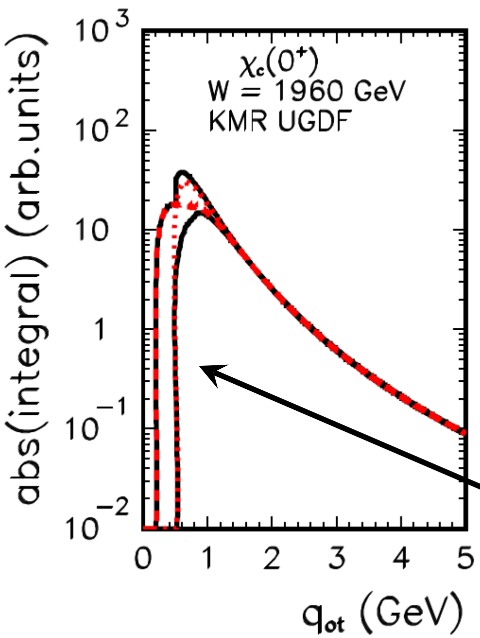
"minimal prescription" $Q_{1,t}^2 = \min\{q_{0,t}^2, q_{1,t}^2\}$, $Q_{2,t}^2 = \min\{q_{0,t}^2, q_{2,t}^2\}$

$$f_g^{KMR}(x, x', Q_t^2, \mu^2; t) = f_g^{KMR}(x, x', Q_t^2, \mu^2) \exp(b_0 t) \qquad \text{with } b_0 = 2 \text{ GeV}^{-2}$$

skewed distributions $f_g^{KMR}(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T(Q_t^2, \mu^2)} xg(x, Q_t^2) \right]$

Sudakov f.f. ***integrated density,*** ***$Q_t > Q_0$***

$|I(q_{0t}; t_1 = \text{-}0.1 \text{ GeV}^2, t_2 = \text{-}0.1 \text{ GeV}^2, \phi = \pi)|$



"hard" scale $\mu = M_\chi / 2$

$$\mathcal{M}(y, t_1, t_2, \phi) = \int dq_{0,t} \, I(q_{0,t}; y, t_1, t_2, \phi)$$

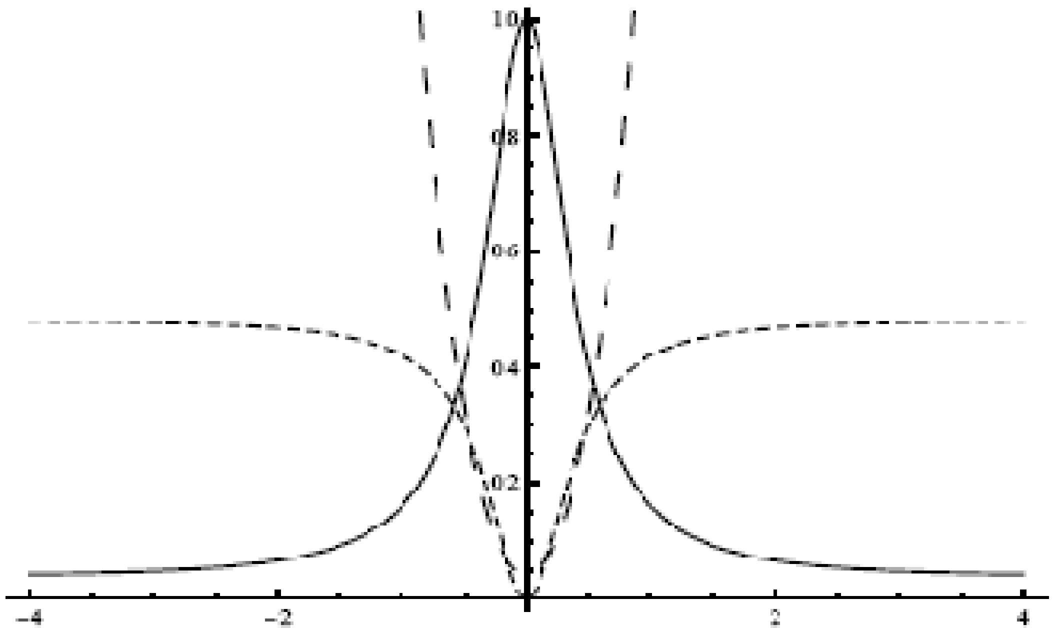
main contribution to the amplitude comes from very small gluon transverse momenta!

different prescriptions for effective Qt

huge sensitivity to details in the nonperturbative domain $Q_t^2 < Q_0^2$

Helicity amplitudes

- Massive particle -> 2J+1 states (rest frame)
- Massless -> 2 helicities (no rest frame)
- Fast :dominance of maximal helicity
- y dependence:



- Helicity 1
- Helicity 0

Conclusions

- Inclusive kT factorization – large J=1,2 contribution
- Exclusive (Durham) kT – also (enhanced by survival probability spin dependeтce – talk of VA Khoze)
- UGD dependence – crucial test
- Maximal helicity enhancement